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Discussion paper: An electromagnetic mechanism of solar-terrestrial relations

A. G. Kolesnik, A. S. Borodin, S. A. Kolesnik, and S. V. Pobachenko

Siberian Physical and Technical Institute, Tomsk State University, Tomsk, Russia

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[1] Studies of the electromagnetic mechanism of solar-terrestrial relations and their influence on the states of separate systems of a human organism are discussed. Quantitative estimates of the level of statistical relations between the characteristics of the cardiovascular system and human brain activity and parameters of the fundamental modes of the near-Earth resonators have been obtained. *INDEX TERMS:* 0426 Biogeosciences: Biosphere/atmosphere interactions; 2162 Interplanetary Physics: Solar cycle variations; 2712 Magnetospheric Physics: Electric fields; *KEYWORDS:* Mechanism of solar-terrestrial relations; Geomagnetic impact of humans; Near-Earth resonator.

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1. Introduction

[2] During several recent decades, the most challenging problem in the physics of solar-terrestrial relations has been the search for the mechanisms through which different events and processes on the Sun manifest themselves in the biosphere of the Earth and in the near-Earth space. Pioneering efforts in the formulation and solution of this problem were undertaken by *Chizhevskiy* [1995]. Currently, many aspects of this problem are well understood and even seem trivial, such as, for instance, changes in the conditions in different regions of the planet depending on the season and time of day which are determined by a mutual position of the Earth and the Sun in space. A considerable progress in understanding of the mechanisms through which the solar events with a quasiperiodical character (solar activity with 11-year, 27-day, and other quasi-periods) manifest themselves in the near-Earth space (the magnetosphere, the ionosphere, and the upper and lower atmosphere of the Earth) has been made. There are more modest achievements in the establishment of the mechanisms by which the nonstationary solar processes that do not exhibit quasiperiodicity and that are characterized by lifetimes from tens of seconds to several hours (for instance, a solar flare) affect the near-Earth space. These achievements have been treated in a number of books [see, e.g., *Akasofu and Chapman*, 1974; *Banks and Kockarts*, 1973; *Brunelli and Namgaladze*, 1988; *Danilov and Vlasov*, 1973; *Ivanov-Kholodnyy and Nikolskiy*, 1969; *Kolesnik et al.*, 1993; *Krinberg and Tashchilin*, 1984]. Though it is a long way to the solution of the problem for the near-Earth space (the problems of space climate and weather, etc., still remain unresolved), the results obtained in the investigations carried out during the recent decades are impressive.

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[3] The situation with the mechanisms of influence of solar processes and events on the biosphere of the Earth as a whole and on a man in particular is quite different. The data accumulated up to now convincingly demonstrate that there is a connection between solar events and the psychophysiological state of an individual [see, e.g., *Chizhevskiy*, 1995; *Gichev and Gichev*, 1999; *Gnevyshev and Ol'*, 1971; *Ptitsina et al.*, 1998]. The major part of these empirical data is concerned with establishing a correlation between solar activity and psychophysiological states of individuals. These are lethal outcomes of different diseases, exacerbations of diseases, changes in the frequency of traffic accidents, etc. There is a smaller amount of empirical data on the relation between nonstationary processes on the Sun and the state of a human organism. This can be explained by the difficulties encountered in the investigations of correlation relations because of relatively short lifetimes of nonstationary events. As far as the mechanisms responsible for these correlations are concerned, the solution of this problem has not advanced beyond few rather doubtful hypotheses.

[4] Here the hypothesis of *Kobrin* [1982] should be mentioned. On the basis of the experimental fact that the lag of the maximum of catastrophes (traffic accidents and cardiovascular catastrophes) behind powerful solar flares does not exceed 24 hours, Kobrin put forward the hypothesis that the influence of solar activity on a human organism can be effected through natural electromagnetic fields generated by

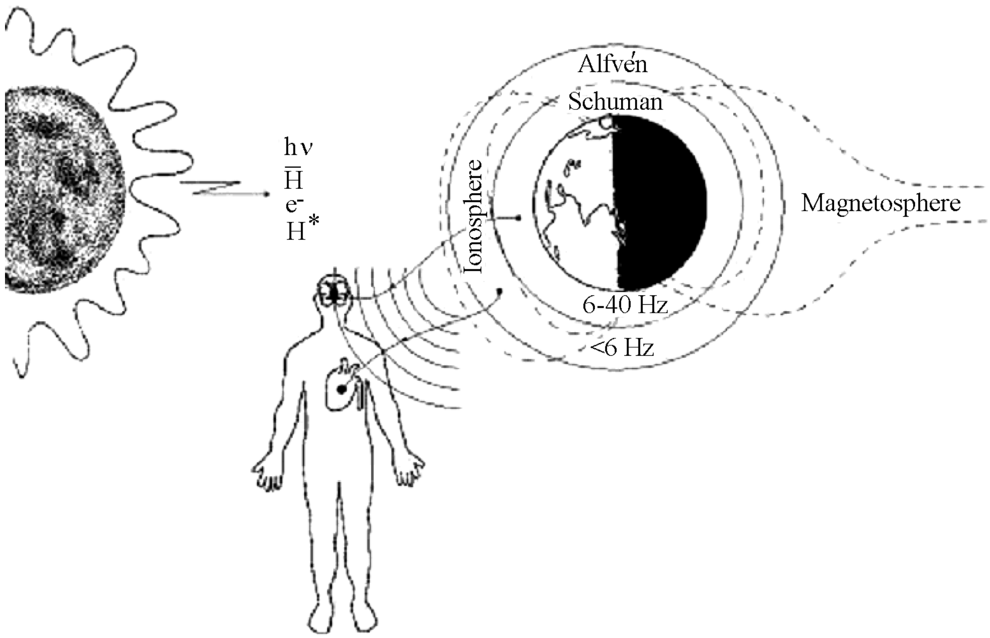

Figure 1. A qualitative picture of the resonance electromagnetic mechanism of solar-terrestrial relations.

the Schumann resonator or short-period oscillations of the geomagnetic field.

[5] Thus the problem of the mechanisms through which solar activity affects the human organism still remains unresolved. The goal of the work described here was to reveal such a mechanism and to justify it on the basis of experimental data.

2. Background

[6] As noted above, the state of the near-Earth space is governed to a large extent by solar events and processes with different characteristic times. These events and processes are accompanied by considerable changes in basic solar factors affecting the near-Earth space. First of all, these are X-ray and extreme ultraviolet radiation of the Sun ($\lambda \leq 1200$ Å) whose absorption in the Earth's upper atmosphere leads to ionization of neutral atoms and molecules, i.e., formation of the ionospheric plasma at altitudes above $\sim$60 km [*Ivanov-Kholodnyy and Nikolskiy*, 1969]. The second factor is the solar wind which consists of fluxes of electrons and protons (whose velocities at the Earth's orbit amount to 300–1000 km s^{-1}) with a frozen-in interplanetary magnetic field. The solar wind determines to a great degree the geometry and energetics of separate structures of the Earth's magnetosphere which, in their turn, exert an influence on the ionosphere formation [*Akasofu and Chapman*, 1974]. At last, one more factor typically accompanying solar flares should be mentioned. This is fluxes of highly energetic electrons ($E \geq 20$ keV) and protons ($E \geq 20$ MeV). These fluxes also affect the state of the Earth's magnetosphere and, eventually, ionosphere [*Mizun*, 1980].

[7] It is also well known that, owing to the presence of the ionosphere, the near-Earth space contains two global natural resonators where electromagnetic waves (EMW) of definite frequencies can propagate at very long distances almost without attenuation. The first resonator is the space confined between two conducting quasi-spherical surfaces, one of which is the Earth's surface and the other is the ionosphere base [*Balokh et al.*, 1977]. Its fundamental resonance frequencies are above 6 Hz, and the main source of its excitation is intraatmospheric thunderstorms [*Borodin and Kolesnik*, 2001].

[8] The second quasi-spherical resonator represents the space confined between the lower ionosphere and the region of the ionosphere that lies above the basic maximum of electron concentration ($h \geq 1000$ km) [*Belyaev et al.*, 1989]. This resonator is referred to as the Alfvén resonator, and its resonance frequencies lie in the range < 6 Hz. The sources of its excitation are in the Earth's atmosphere and magnetosphere.

[9] The next group of prerequisites is related to specific features of the frequency rhythms of separate systems of a human organism. First of all, these are frequency rhythms of the human brain. It is known that a human brain generates the electromagnetic fields in the frequency range $1 \div 40$ Hz. They have a resonance character and form α, β, and other biorhythms [*Dolgato and Kholodov*, 1987]. In particular, for the α rhythm the resonance frequencies lie in a range of 8–12 Hz, and for the β rhythm the resonance frequencies are in a range of 14–21 Hz. Thus the frequency range of the electromagnetic fields generated by the human brain is rather close to the frequency range of the Schumann resonator.

[10] The cardiovascular system of a human organism is also able to generate electromagnetic fields in the range characterized by a set of harmonics having different frequencies and intensities [*Amoff*, 1984], with the fundamental fre-

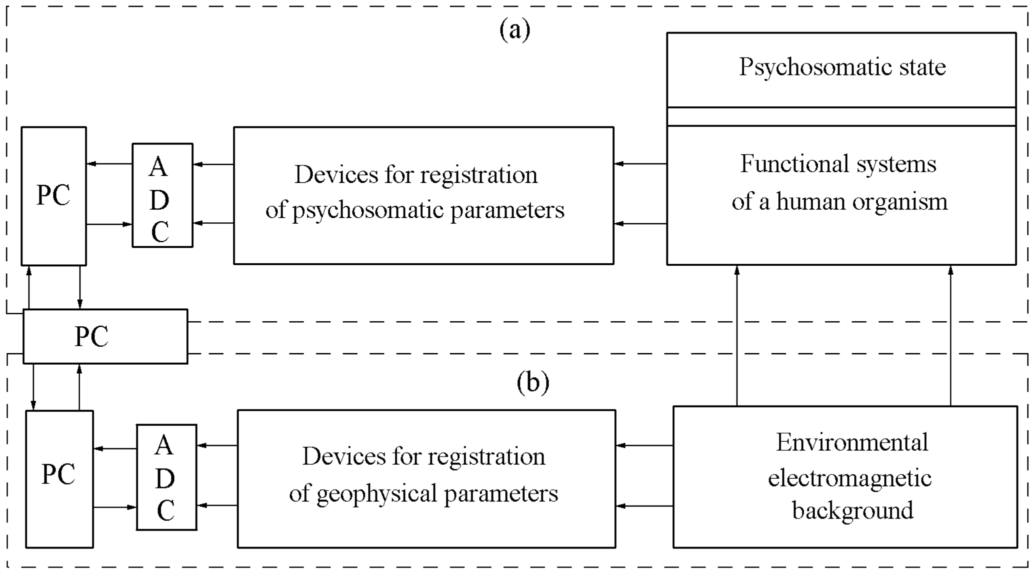

Figure 2. Block diagram illustrating how monitoring of the states of (a) basic functional systems of the human organism and (b) environmental electromagnetic fields was performed.

quency being in the range $0.8 \div 2.5$ Hz. It is evident that, by the frequency range, the biorhythm of the cardiovascular system of the human organism is similar to the range of the Alfvén resonator.

3. A Qualitative Picture of the Mechanism

[11] The prerequisites considered in section 2 allow one to suggest a qualitative picture of the resonance electromagnetic mechanism of solar-terrestrial connections and their influence on the states of separate systems of the human organism. The suggested mechanism is shown schematically in Figure 1. The essence of the mechanism is as follows. The nonstationary processes occurring on the Sun are accompanied by considerable changes in the basic factors that affect the near-Earth space, i.e., X-ray and extreme ultraviolet radiation ($h\nu$), fluxes of highly energetic charged particles (e^-, H^+), and the solar wind with a frozen-in magnetic field ($\mathbf{H}$). Through a large variety of fairly complicated physical-chemical processes, these factors give rise to changes in basic characteristics of the near-Earth space, including the Earth's ionosphere. This means that fundamental characteristics of the global natural Alfvén and Schumann resonators (dielectric permeability of the resonators and their geometric characteristics) undergo changes. As a result, the quality factors of these resonators and the frequencies of their fundamental modes change.

[12] Since during millions of years the human organism has been subjected to a continual action of the electromagnetic fields generated by the global near-Earth resonators, it is quite reasonable to suppose that it is fully adapted to these fields. Changes in the characteristics of these fields (resonance frequencies, intensities) must find response in the states of separate systems of the human organism.

4. Experiment Aimed at Justification of the Mechanism

[13] The most appropriate experiment aimed at justification of the suggested mechanism is simultaneous monitoring of the characteristics of separate human organisms and parameters of the electromagnetic fields generated by the near-Earth resonators during a fairly long time interval that would include most important events occurring on the Sun and eventually determining its activity. To this end, two measuring-calculating systems are used. One system provides detection and analysis of the electromagnetic background of the environment, including the frequency range of the near-Earth resonators (0.1–30) Hz [*Kolesnik*, 1998; *Kolesnik et al.*, 1997]. A computer-aided fast data processing including examination of the spectra of the detected signals, their storage on magnetic media, and formation of databases for subsequent analysis is carried out. The second system provides continuous monitoring of the key characteristics of the functional states of a human organism including the cardiovascular and nervous systems [*Borodin et al.*, 1997; *Kolesnik*, 1998]. These two measuring-calculating systems are synchronized in time, which allows parallel (synchronous) monitoring of both the parameters of the environmental electromagnetic fields and characteristics of the functional states of the human organism (see Figure 2).

[14] In this work, the data obtained in the monitoring carried out from 1994 to 2003, i.e., during the period embracing nearly the entire 11-year solar cycle with the maximum

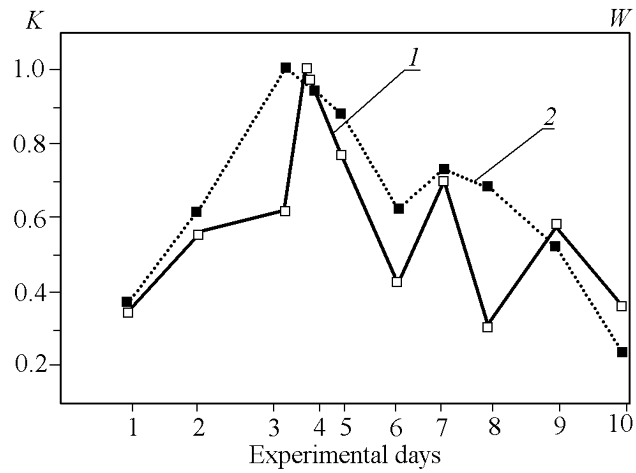

Figure 3. Dynamics of daily averaged correlation coefficients between power spectral density of EEG and ELF EMF in the range of exogenous determination (6–16 Hz) and solar activity level W. The data are given for 10 days, the sample is 15 volunteer research subjects.

solar activity in 2002 and minimum activity in 1997, were used. Essential features of the monitoring of the states of the functional systems of a human organism which should be noted here are the 24-hour registration and the condition of "physiological rest" for the volunteers participating in the investigations. The necessity to meet these requirements was due to the facts that (1) the circadian cycle is the fundamental cycle in the adaptive activity of an organism and (2) an active behavior can considerably modify important variables of the basic functional systems. In other words, a correct analysis of experimental data would be problematic if these conditions were not fulfilled. Technical details of recording of electrocardiograms (ECG) and electroencephalograms (EEG) were standard to a large degree [*Borodin and Kolesnik*, 2001].

5. Experimental Results and Discussion

[15] Let us consider the results obtained in the experiments aimed at justification of the suggested mechanism by discussing, as an example, how the human brain activity evaluated from the electroencephalogram (EEG) obtained at a measuring-calculating system depends on a set of solar and geophysical factors of the environment. Several series of the investigations of the correlation between variations in the EEG parameters and fundamental characteristics of the background electromagnetic fields of the Schumann resonance range have convincingly demonstrated that variations in the biorhythmic activity of the human brain under the condition of a physiological rest correlate with changes in the electromagnetic fields (EMF) of the extremely low-frequency (ELF) range (Schumann resonances). The level of correlation interrelations between changes in the amplitude characteristics in the range of exogenous determination of the EEG rhythms and electromagnetic background fluctuations has been found to range from 0.2 to 0.8 ($\alpha = 0.95$) on different experimental days for a sample of volunteer research subjects. The range of exogenous determination is the frequency range in which the effect of external electromagnetic fields on living systems has a maximum bioefficiency. In addition, it has been inferred from the data obtained in the long-term monitoring that the dynamics of the correlation between the parameters of the EEG activity and the ELF variations of the EMF exhibits a stable daily variation involving higher levels of correlation in the morning and evening hours. This can be attributed to pronounced changes in the parameters of the Schumann resonances in the dynamics of their daily variation in these hours. Thus the fact that fluctuations in the parameters of the Schumann resonances affect variations in spontaneous electrical activity of the human brain can be thought to be experimentally verified.

[16] It is now reasonable to evaluate the influence of global indexes of solar and geomagnetic activity on the revealed regularities in the context of the suggested mechanism. In this connection, all the results of the experimental investigations for sample statistics were inspected with the aim of revealing whether the correlations between the parameters of the range of exogenous determination of the EEG and the ELF variations of the EMF are influenced by the solar and geomagnetic activities. Figure 3 shows the 10-day dynamics of daily averaged correlation coefficients between the parameters of EEG and ELF EMF and the solar activity level (Wolf numbers). The trends in the variations of the values considered are seen to be similar. A linear correlation analysis of the presented data has shown that the correlation coefficient is 0.75 ($\alpha = 0.95$). The relationships with the dynamics of the geomagnetic activity represented by the *Ap* indexes are similar.

[17] The obtained results suggest that there is a general regularity, i.e., as the levels of solar and magnetic disturbances increase, the degree of correlation between the characteristics of the neuro-dynamic activity and the parameters of the Schumann resonances become higher. This regularity allows us to interpret the available data on exacerbations of a number of diseases, the so-called dynamic diseases, when a disturbance of the solar or geomagnetic activity occurs. It is known that the range of adaptive abilities of an organism appreciably depends on the general state of the organism. If nosological deviations take place, this range becomes substantially narrower. Because of this, the coordinating system of the exogenous regulation of rhythms can fail to follow the dynamics of the exogenous agent of the physical nature, which potentially can cause a temporal mismatch of a set of biological rhythms or violation of the homeostasis of functional systems.

[18] Therefore, by modifying the state of the Schumann resonator, solar and geomagnetic disturbances indirectly affect the functional state of a human organism, in particular the levels of neurodynamics and hence the biorhythmic activity of the organism as a whole.

[19] Let us consider the results obtained in the experiments aimed at justification of the resonance mechanism of solar-terrestrial connections taking the cardiovascular system of a human being as an example. Figure 4 presents

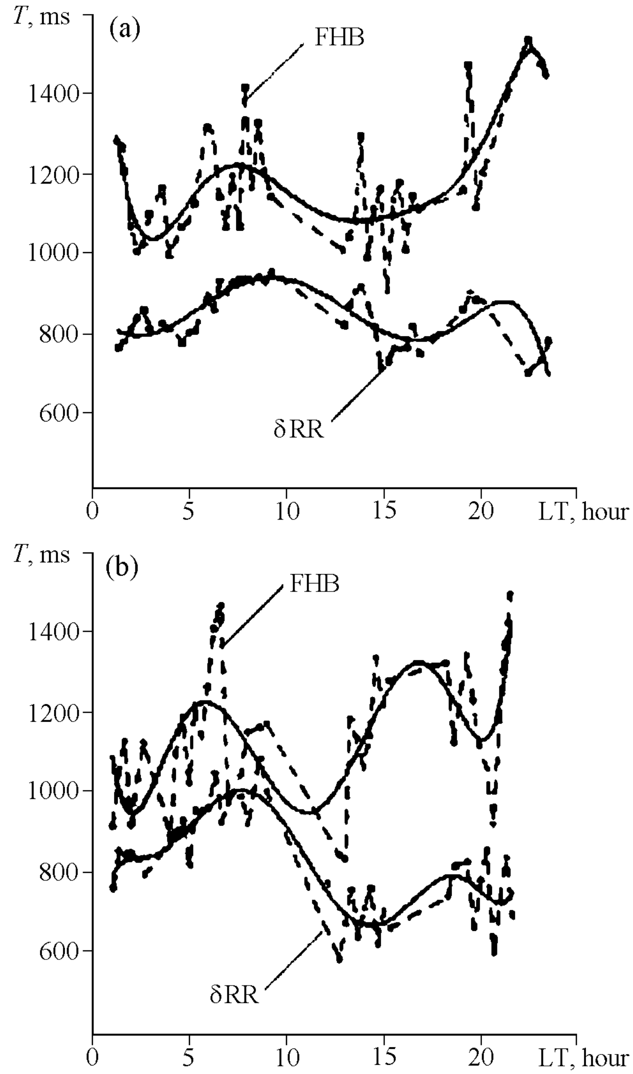

Figure 4. Daily trends in variations of averaged values of FHB and δRR. The abscissa is the local time, the ordinate axis shows periods in ms. Volunteer research subjects are (a) L.K. (19 August 1995) and S.K. (b) (20 August 1995).

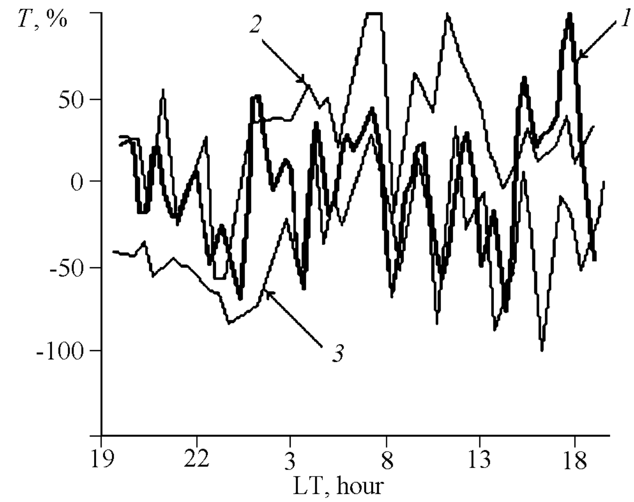

Figure 5. Correlation between biorhythmic activity of the human cardiovascular system and natural fluctuations in the EMF of the ELF range. The ordinate axis shows centered and normalized values of periods in %; 1, daily dynamics of the FHB; 2, 3, daily dynamics of the envelopes of variations in δRR for a pooled sample. The abscissa is the local time.

changes in the daily dynamics of the frequency of the fundamental harmonic of the electromagnetic background (FHB) in the frequency range from 0.8 to 2.5 Hz and variations in the period of heart contractions (δRR) for two volunteer research subjects from a sample of 10 persons. The dashed line in the figure is the linear interpolation of experimental results, and the solid line shows the polynomial approximation of the data. It can be seen that there is a pronounced correlation between changes in the individual circadian rhythm and variations in one of the components of the natural electromagnetic background.

[20] It is obvious that correlated changes in the parameters considered above do take place, however their regularity and quantitative degree of correlation with the magnitude of variation in the FHB period are different for different volunteer research subjects. One of possible factors responsible for a lack of uniqueness in the response of functional systems of a human organism is a varying individual psychosomatic state. This means that variations in the absolute values have individual characteristic correlation relations with the dynamics of variations in the fundamental harmonic of the electromagnetic background (FHB). An attempt was made to reveal a common tendency in possible modulations of the level of functioning of the cardiovascular system (δRR) and changes in the FHB. To this end, 24-hour measurements of δRR in four volunteer research subjects at one and the same time were carried out and, simultaneously, changes in the period of the FHB of the ELF range were measured. Using individual changes in the cardio intervals combined relative to the time axis, envelopes of extrema were drawn (Figure 5).

[21] It has been found that the actual dynamics of the variables discussed, while appreciably differing in each individual case, is characterized by a rather high statistically significant correlation (Pearson's coefficient of correlation is equal to 0.4 at $\alpha = 0.05$). Analysis of the time intervals of the additive components of δRR corresponding to the presented data has shown that the major contribution to variations in the heart activity cycle comes from changes in the durations of the atrium excitation interval and constituents of the relaxation phase interval. Analysis has also revealed that the character of the correlated variations of the electrocardiogram portions depends on the individual typological features and the circadian rhythm phase of a volunteer research subject.

[22] Because of an insufficient amount of the obtained data, the cause-and-effect relationships between variations in the processes investigated cannot be revealed, however a strong correlation between the dynamics of the cardiovas-

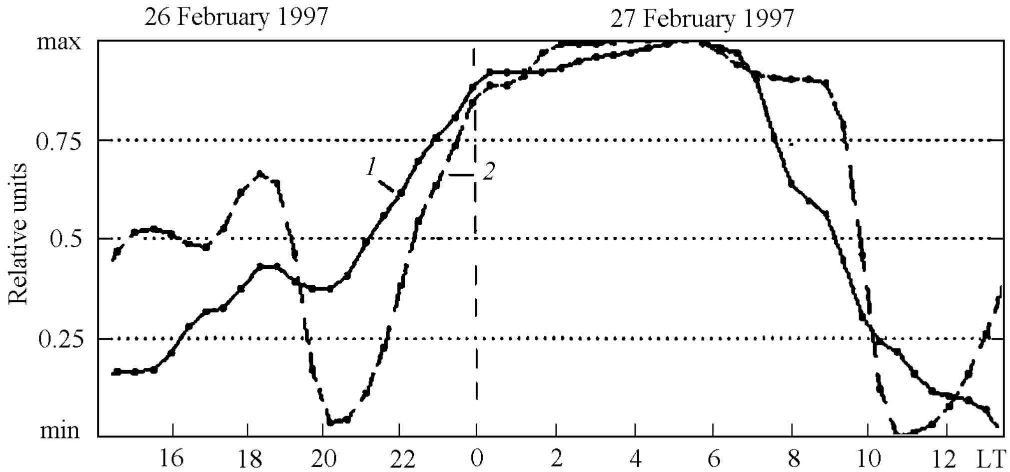

Figure 6. Low-frequency components of the daily variations in the period of heart contractions and eastward component of the magnetic field vector. The abscissa axis shows local time in hours, the ordinate axis shows normalized values of variables in relative units. The volunteer research subject is P. S.; 1, δY, and 2, δRR.

cular system parameters and the dynamics of the period of the separated out mode of the background EMF of the ELF range suggests that natural electromagnetic fields of the ELF range belong to significant ecological factors even in magnetically quiet days. The fact that the responses of the cardiovascular system have characteristic activity modulations typical of the dynamics of the electromagnetic background of the particular geographical location leads to the conclusion that the hypothesis that this exogenous factor can be one of external synchronizers for oscillatory systems of a human organism has been experimentally confirmed.

[23] Variations in the components of the vector of the magnetic field as a circadian synchronizer are considered from a similar point of view. Results of this investigation are illustrated in Figure 6, where smoothed values of the Y component (δY) of the magnetic field and the period of heart contractions δRR are shown as functions of the time of a day for one of the patients.

[24] If a measure of correlation is taken to be the magnitude of the cross-correlation function, its reliable value for a given volunteer research subject at a zero shift and a confidence probability level of 95% is 0.56 for the eastward component and −0.11 for the northward component. For the vertical component the correlation coefficient is negligible under these conditions. For the entire sample, the partial correlation coefficient of δRR is the highest for the eastward component (0.70), it is equal to 0.60 for the vertical component, and it is negligible for the northward component [*Borodin and Kolesnik*, 2001]. A characteristic feature is that significant correlated changes in the period of heart contractions and pattern of variations in the magnetic field vector components are maintained for time periods of up to tens of seconds (see Figure 7) [*Borodin and Kolesnik*, 2001].

[25] Such regularities should not be underestimated because considerable changes in the pattern of variations of the magnetic field vector components in different frequency ranges can cause a provoked ectopic activity in the patients suffering from diseases of the cardiovascular system.

6. Basic Conclusions and Concluding Remarks

[26] The results obtained in the experiments lead to the following basic conclusions:

[27] 1. Parameters of the cardiovascular system and activity of the human brain correlate (exhibit synchronism of variations) with characteristics of the fundamental modes of the near-Earth resonators. Their cross-correlation function varies in the range 0.2–0.8.

[28] 2. The correlation is controlled by the levels of solar and geomagnetic activities and grows with increasing solar and geomagnetic activity, which confirms the suggested electromagnetic mechanism of solar-terrestrial relations.

[29] To further develop and refine this mechanism, the following steps are to be undertaken.

[30] First, to investigate differences in the behaviors of the levels of correlation between characteristics of the functional systems of a human organism and the electromagnetic field of the near-Earth resonators during the periods of separate nonstationary processes on the Sun (for instance, during solar flares) and the periods of the "quiet" Sun.

[31] Second, to study the dependence of the manifestations of this mechanism on not only variations in frequencies of the fundamental modes of the near-Earth resonators, but also their intensities.

[32] Third, to study whether this mechanism can manifest itself at fractional frequencies of the fundamental modes of the resonators with parametric amplification.

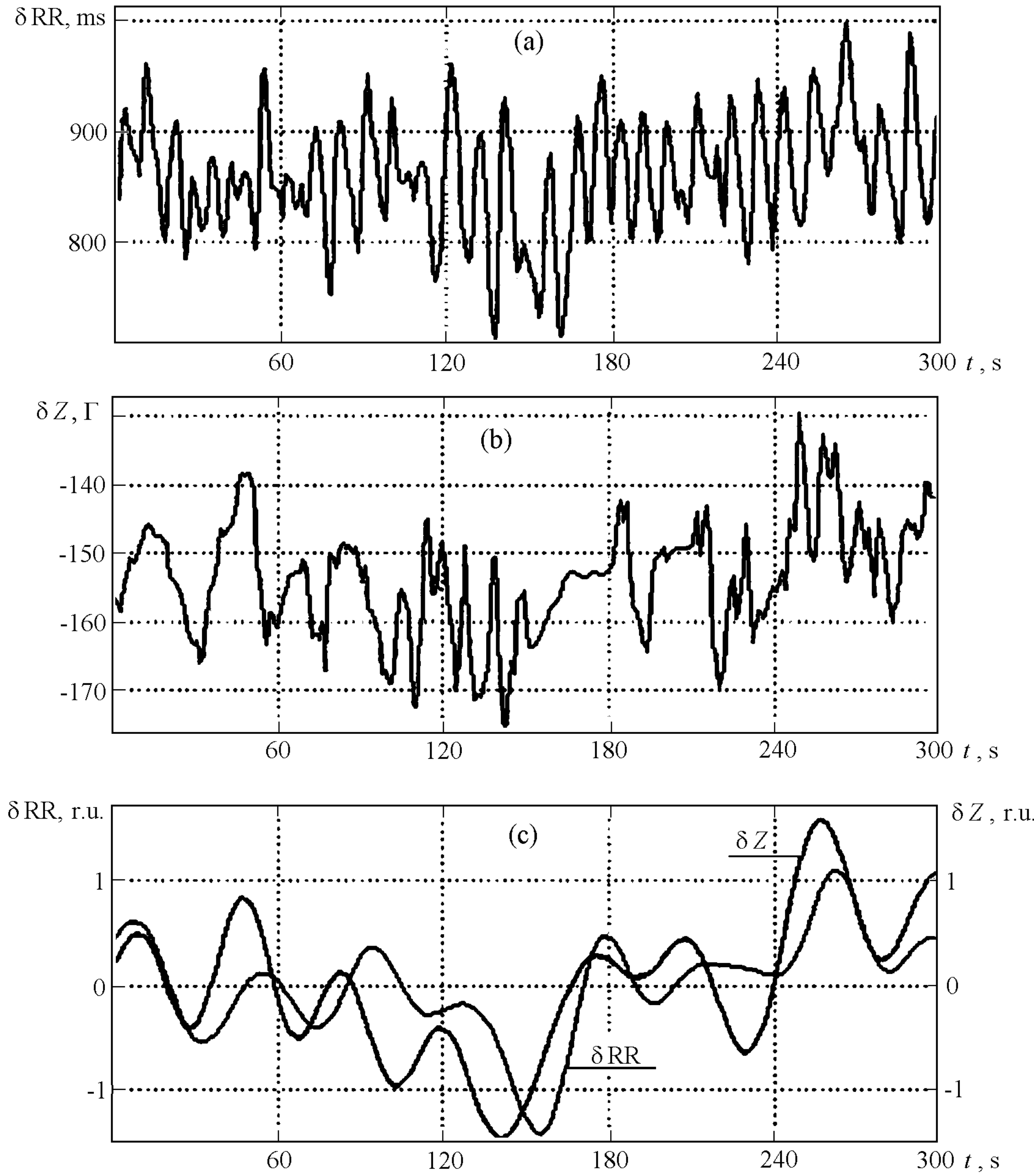

Figure 7. Slow waves of sinus arrhythmia and short-term fluctuations in the vertical component of the MF vector showing (a and b) values of the initial processes and (c) filtered trends of initial realizations). The volunteer research subject was S. A.

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A. S. Borodin, A. G. Kolesnik, S. A. Kolesnik, and S. V. Pobachenko, Siberian Physical and Technical Institute, Tomsk State University, Tomsk, Russia. (kolesnik@elefot.tsu.ru)